CLAIMS

1. An engine comprising:

a variable volume chamber;

inlet valve means controlling admission of charge air into the variable volume chamber;

fuel delivery means for delivering fuel to be mixed with the charge air admitted to the variable volume chamber; and

exhaust valve means for controlling exhaust to atmosphere from the variable volume chamber of combusted gases resulting from combustion in the variable volume chamber of the fuel with the admitted charge air;

wherein:

the engine has a first operating mode in which the inlet valve means admits charge air into the variable volume chamber, the fuel delivery means delivers fuel which is mixed with the admitted charge air, the mixture of fuel and charge air is compressed by the variable volume chamber reducing in volume, the compressed mixture of fuel and air combusts, the combusted gases expand and force the variable volume chamber to increase in volume and the expanded combusted gases are exhausted to atmosphere from the variable volume chamber via the exhaust valve means;

characterised in that the engine additionally comprises:

a reservoir for storing compressed air which is connected to the variable volume chamber; and

gas flow control valve means controlling flow of air between the variable volume chamber and the reservoir for storing compressed air;

and characterised in that the engine has at least two additional operating modes:

a second operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the gas flow control valve means allows the compressed air to flow from the variable volume chamber to the reservoir to be stored therein; and

a third operating mode in which the gas flow control valve means allows compressed air to flow from the reservoir into the variable volume chamber and thereafter expand to force the variable volume chamber to increase in volume, the expanded air subsequently being exhausted to atmosphere.

2. An engine as claimed in claim 1 wherein the expanded air is exhausted to atmosphere via the exhaust valve means.

3. An engine as claimed in claim 1 wherein the expanded air is exhausted to atmosphere via the inlet valve means.

4. An engine as claimed in any one of claims 1 to 3 which has a fourth operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the

exhaust valve means allows the compressed air to be exhausted to atmosphere.

5. An engine as claimed in any one of claims 1 to 3 which has a fourth operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the inlet valve means allows the compressed air to be exhausted to atmosphere.

6. An engine as claimed in claim 4 or claim 5, which has a fifth operating mode in which: air or combusted gases is/are trapped in the variable volume chamber by closing all of the inlet valve means, the exhaust valve means and the gas flow control valve means, and in which the variable volume chamber with the trapped air or combusted gases operate(s) as a gas spring.

7. An engine as claimed in claim 6, wherein the fuel delivery means is deactivated whilst the engine is operating in the fifth operating mode.

8. An engine as claimed in any one of claims 4,5, 6 or 7 wherein the fuel delivery means is deactivated whilst the engine is operating in the fourth operating mode.

9. An engine as claimed in any one of claims 1 to 3 which has a fourth operating mode in which the gas flow control valve means admits compressed air to flow from the reservoir into the variable volume chamber in an intake stroke of the engine for mixing with fuel

delivered by the fuel delivery means, with the mixture of fuel and compressed air being further compressed by the variable volume chamber reducing in volume and the further compressed mixture combusting and subsequently expanding to cause the variable volume chamber to increase in volume and with the expanded combusted gases exhausted to atmosphere via the exhaust valve means.

10. An engine as claimed in claim 9 wherein in the fourth operating mode during the intake stroke of the engine the inlet valve means opens to allow charge air to be drawn into the variable volume chamber during an initial part of the intake stroke and then the inlet valve means closes and subsequently the gas flow control valve mans opens to admit the compressed air into the variable volume chamber to be mixed with the air previously admitted via the inlet valve means.

11. An engine as claimed in any one of the preceding claims wherein when the engine is operating in the third operating mode then the engine can operate a two-stroke cycle with the gas flow control valve means admitting compressed air into the variable volume chamber during each downstroke.

12. An engine as claimed in claim 11 wherein when the engine is operating in the third operating mode then the engine can operate a four-stroke cycle with an intake stroke in which the inlet valve means allows fresh charge air to be drawn into the variable volume chamber, a compression stroke in which the charge air admitted via

the inlet valve means is compressed, a power stroke in which the gas flow control valve means admits compressed air into the variable volume chamber to supplement the air previously compressed in the compression stroke and an exhaust stroke in which expanded air is expelled from the variable volume chamber.

13. An engine as claimed in any one of the preceding claims wherein the fuel delivery means is deactivated whilst the engine is operating in the second operating mode.

14. An engine as claimed in any one of the preceding claims wherein the fuel delivery means is deactivated whilst the engine is operating in the third operating mode.

15. An engine as claimed in any one of the preceding claims wherein the air compressed in the variable volume chamber in the second operating mode of the engine is compressed to a pressure in the range 10 to 20 bar.

16. An engine as claimed in any one of the preceding claims wherein the reservoir comprises a light plastic pressure vessel.

17. An engine as claimed in any one of claims 1 to 15 comprising additionally a pump powered by the engine which receives compressed air expelled from the variable volume chamber and compresses the air further before the compressed air is delivered to the reservoir.

18. An engine as claimed in claim 10 wherein the pump raises the pressure of the compressed air from an initial pressure in the range 10 to 20 bar to a higher pressure of 100 to 100 bar.

19. An engine as claimed in any one of claims 1 to 15 comprising additionally an engine-driven supercharger which pressurises the charge air admitted into the variable volume chamber via the inlet valve means.

20. An engine as claimed in any one of claims 1 to 15 comprising additionally an electrically-driven turbocharger which pressurises the charge air admitted into the variable volume chamber via the inlet valve means.

21. An engine as claimed in claims 17 to 20 wherein the reservoir comprises a steel pressure vessel.

22. An engine as claimed in any one of the preceding claims, wherein the variable volume chamber is defined between a piston and a surrounding cylinder, the piston reciprocating in the cylinder and the piston being connected to a crankshaft of the engine.

23. An engine as claimed in any one of the preceding claims wherein each of the inlet valve means, the exhaust valve means and the gas flow control valve means comprises a valve operated by a hydraulic actuator individual to the valve and all of the hydraulic

actuators are controlled by a common electronic controller, the electronic controller receiving signals from a plurality of sensors and the electronic controller varying operation of the hydraulic actuators and thereby operation of the valves in order to switch operation of the engine between the operating modes thereof.

24. A vehicle comprising an engine as claimed in claim 23 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and a sensor measuring pressure of air stored in the reservoir and wherein the electronic controller on detecting that the vehicle is decelerating whilst the reservoir is depleted varies operation of the hydraulic actuators so that the engine operates in the second operating mode.

25. A vehicle as claimed in claim 24 which has an automatic transmission with a variable gear ratio and wherein the electronic controller controls the transmission to lower the gear ratio when the vehicle is decelerating in order to increase revolutionary speed of the engine.

26. A vehicle comprising an engine as claimed in claim 24 or 25 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the valve is decelerating whilst the reservoir is

full varies operation of the hydraulic actuators so that the engine operates in the fourth operating mode.

27. A vehicle comprising an engine as claimed in claim 24 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and to requirements of a driver and the electronic controller on detecting that the vehicle is stationary and the driver wishes the vehicle to start moving controls operation of the hydraulic actuators so that the engine operates initially in the third operating mode and then, as speed of the vehicle increases, the operation of the hydraulic actuators is varied so that the engine switches to the first operating mode.

28. A vehicle as claimed in claim 27 wherein the vehicle commences motion without use of a clutch.

29. An engine comprising:

a plurality of variable volume chambers;

inlet valve means controlling admission of charge air into the variable volume chambers;

fuel delivery means for delivering fuel to be mixed with the charge air admitted to the variable volume chambers; and

exhaust valve means for controlling exhaust to atmosphere from the variable volume chambers of combusted gases resulting from combustion in the variable volume chambers of the fuel with the admitted charge air; wherein

the engine can operate at least one of the plurality of variable volume chambers in a plurality of different operating modes; and

the engine can operate each variable volume chamber in a first operating mode in which the inlet valve means admits charge air into the variable volume chamber, the fuel delivery means delivers fuel which is mixed with the admitted charge air, the mixture of fuel and charge air is compressed by the variable volume chamber reducing in volume, the compressed mixture of fuel and air combusts, the combusted gases expand and force the variable volume chamber to increase in volume and the expanded combusted gases are exhausted to atmosphere from the variable volume chamber via the exhaust valve means;

characterised in that:

the engine additionally comprises:

a reservoir for storing compressed air which is connected to at least one of the plurality of variable volume chambers; and

gas flow control valve means controlling flow of gas between at least one of the variable volume chambers and the reservoir for storing compressed air;

and characterised in that the engine can operate at least one of the plurality of variable volume chambers in at least two additional operating modes:

a second operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the gas flow control valve means allows the compressed air to flow

from the variable volume chamber to the reservoir to be stored therein; and

a third operating mode in which the gas flow control valve means allows compressed air to flow from the reservoir into the variable volume chamber and thereafter expand to force the variable volume chamber to increase in volume, the expanded air subsequently being exhausted to atmosphere.

30. An engine as claimed in claim 29 wherein in the third operating mode the expanded air is exhausted to atmosphere via the exhaust valve means.

31. An engine as claimed in claim 29 wherein in the third operating mode the expanded air is exhausted to atmosphere via the inlet valve means.

32. An engine as claimed in any one of claims 29 to 31 wherein the engine can simultaneously operate a first of the variable volume chambers according to the first operating mode while operating a second of the variable volume chambers according to the second operating mode whereby some of the work derived from the expansion of the combusted gases in the first variable volume chamber is used to compress air in the second variable volume chamber.

33. An engine as claimed in any one of claims 29 to 32 wherein each variable volume chamber is defined between a stationary element and a movable element and all of the movable elements are connected to a common power output

mechanism whereby work derived from expansion of combusted gases can be output from the engine and also transferred between the movable elements.

34. An engine as claimed in claim 33 wherein the stationary elements are cylinders in a cylinder block and the movable elements are pistons which reciprocate one in each of the cylinders and the power output mechanism comprises a crankshaft to which all of the pistons are connected.

35. An engine as claimed in any of claims 29 to 34 wherein each of the inlet valve means, the exhaust valve means and the gas flow control valve means comprises a valve operated by a hydraulic actuator individual to the valve and all of the hydraulic actuators are controlled by a common electronic controller, the electronic controller receiving signals from a plurality of sensors and varying operation of the hydraulic actuators and thereby the valves in order to control the mode of operation of each variable volume chamber of the engine.

36. An engine as claimed in claim 35 wherein the plurality of sensors includes sensors measuring parameters relating to load on the engine and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the engine is part loaded and that the reservoir is depleted controls operation of the hydraulic actuators so that at least a first variable volume chamber is operating in the first operating mode and delivering power output from the

engine and at least a second variable volume chamber is operating in the second operating mode and compressing air for delivery to the reservoir.

37. An engine as claimed in claim 35 wherein the plurality of sensors includes sensors measuring parameters relating to load on the engine and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the engine is part loaded and that the reservoir is full controls operation of the hydraulic actuators so that first variable volume chamber is operating in the first operating mode and delivering power output from the engine and at least a second variable volume chamber is deactivated by closing the inlet valve means, the exhaust valve means and the gas flow control valve means specific thereto with air or combusted gases trapped in the second variable volume chamber which thereby functions as a gas spring.

38. An engine as claimed in any one of claims 29 to 31 wherein the plurality of variable volume chambers are interconnected by conduit means and when the engine is operating in the second operating mode then the admitted charge air admitted into the said variable valve chamber and compressed therein when allowed to flow from the chamber by the gas flow control volume means flows to at least a second variable valve chamber in which the air is compressed further before flowing to the variable volume chamber to be stored therein.

39. An engine as claimed in any one of claims 29 to 31 wherein the plurality of variable volume chambers are interconnected by conduit means and when the engine is operating in the third operating mode then the air expanded in said variable volume chamber is exhausted via the exhaust means to at least a second variable volume chamber for further expansion therein before the air is exhausted to atmosphere.

40. A method of operating an engine which has a plurality of variable volume chambers each defined by a piston reciprocating in a cylinder, the pistons being connected to a common mechanism for delivering power output from the engine, the method comprising operating the engine in a plurality of different modes of operation including:

a first operating mode in which a mixture of fuel and air is combusted in each variable volume chamber with expansion of combusted gases forcing the pistons to move and with the expanded combusted gases exhausted to atmosphere;

the method being characterised by:

a second operating mode in which a mixture of fuel and air is combusted in at least a first variable volume chamber with expansion of combusted gases forcing the relevant piston to move and with the expanded combusted gases exhausted to atmosphere and in which in at least a second variable volume chamber air is compressed and then the compressed air is delivered to and stored in a reservoir of compressed air; and

a third operating mode in which compressed air stored in the reservoir is admitted into at least one variable volume chamber and the admitted compressed air allowed to expand with the expanded air then exhausted to atmosphere.

41. A method as claimed in claim 40 wherein in the first operating mode a four-stroke cycle is implemented.

42. A method as claimed in claim 40 or claim 41 wherein in the third operating mode a two-stroke cycle is implemented.

43. A method as claimed in any one of claims 40 to 42 wherein the engine is operated in the first operating mode at high loads and in the second operating mode at part loads.

44. A method as claimed in any one of claims 40 to 43 wherein the engine is started with the engine operating according to the third operating mode and subsequently the operating mode is switched to the first or second operating mode.

45. A valve mechanism for controlling flow of pressurised gas into an engine cylinder of an internal combustion engine, the mechanism comprising:

a poppet valve for opening and closing a transfer port in the cylinder through which gas can flow between a source of pressurised gas and the cylinder, the poppet valve having a valve head and a valve stem;

drive means acting on the valve stem for driving the poppet valve to open the transport port; and

spring means for biassing the poppet valve to close the transfer port; characterised in that:

on the valve stem there is mounted a piston which is slidable in a valve stem chamber provided in the internal combustion engine; and

the valve stem chamber is connected to the source of pressurised gas; whereby:

a force is applied to the piston by the pressurised gas in the valve stem chamber which counteracts a force applied on the poppet valve by exposure of a rear face of the valve head, facing away from the engine cylinder, to the pressurised gas from the source of pressurised gas.

46. A valve mechanism as claimed in claim 45 wherein sealing means is provided between the piston and the valve stem chamber to prevent escape of pressurised gas past the piston.

47. A valve mechanism as claimed in claim 45 or claim 46 comprising an isolating control valve operable to selectively connect and disconnect the valve stem chamber and the source of pressurised gas.

48. A valve mechanism as claimed in any one of claims 44 to 47 wherein the spring means comprises a spring located in the valve stem chamber acting on the valve stem mounted piston.

49. A valve mechanism as claimed in any one of claims 44 to 48 wherein the internal combustion engine has a transfer passage leading from the source of pressurised gas to the engine cylinder and opening into the engine cylinder via the transfer port; and the valve stem cylinder is connected to the transfer passage.

50. A valve mechanism as claimed in any one of claims 44 to 49 wherein the drive means comprises a hydraulic actuator controlled by an electronic controller.

51. An internal combustion engine as claimed in any one of claims 1 to 39 wherein the gas flow control valve means comprises a valve mechanism as claimed in any one of claims 44 to 50.